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Training

Introduction to In-Cylinder Pressure Testing Part 3

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In June 2013 the article “Introduction to in-cylinder pressure testing” covered the running idle compression waveform. In May 2014 “Introduction to in-cylinder pressure testing part II” covered the cranking compression waveform. Cylinder pressure testing is becoming one of the most important new diagnostic tools for a shop to use. This technique provides valuable information to the technician that cannot be obtained in any other way. This waveform can convey such things to the technician as; true Top Dead Center (TDC), camshaft timing, ignition timing, restricted exhaust, intake valve problems, exhaust valve problems, and piston sealing problems in just seconds. By understanding the pressure changes in the combustion chamber hours of diagnostic time can be saved.

It is important to understand that the specific pressure changes that occur within the cylinder are what the in-cylinder pressure waveforms are comprised of. This means that each time the throttle valve is changed the pressure within the cylinder also changes. The three basic throttle pressure states that will be analyzed are; cranking with a closed throttle, running with a closed throttle (Idle), and running Snap throttle (WOT). Each of these pressure states will provide different information to the technician that will aide in the diagnoses of the internal combustion.

The amount of incoming air will change depending on where the throttle valve is located. The throttle valve offers resistance to the air flowing into the engine do to the air entering the engine will be regulated as the throttle valve is moved in comparison to the throttle bore. This difference of air volume flowing into the cylinder causes the in-cylinder pressures to change.

In figure 1 the in-cylinder pressure changes are shown as the engine goes from a closed throttle (Idle) to a Wide Open Throttle (WOT) Revving. During the idle state the throttle is in a closed position. At idle the throttle is allowing only enough air to enter into the engine so that, when mixed with the fuel stock, the power released from the air/fuel charge can overcome the parasitic losses of the engine. These parasitic losses include; engine pumping losses, friction losses, viscometric flow losses (pumping oil), and any external load losses (power steering, alternator, A/C, etc). The amount of air entering the engine at hot unloaded idle can be measured in grams per second and will equal approximately the liter size of the engine. So a 5 liter engine will have approximately 5 grams per second of air flow in order to overcome the patristic losses of the engine.

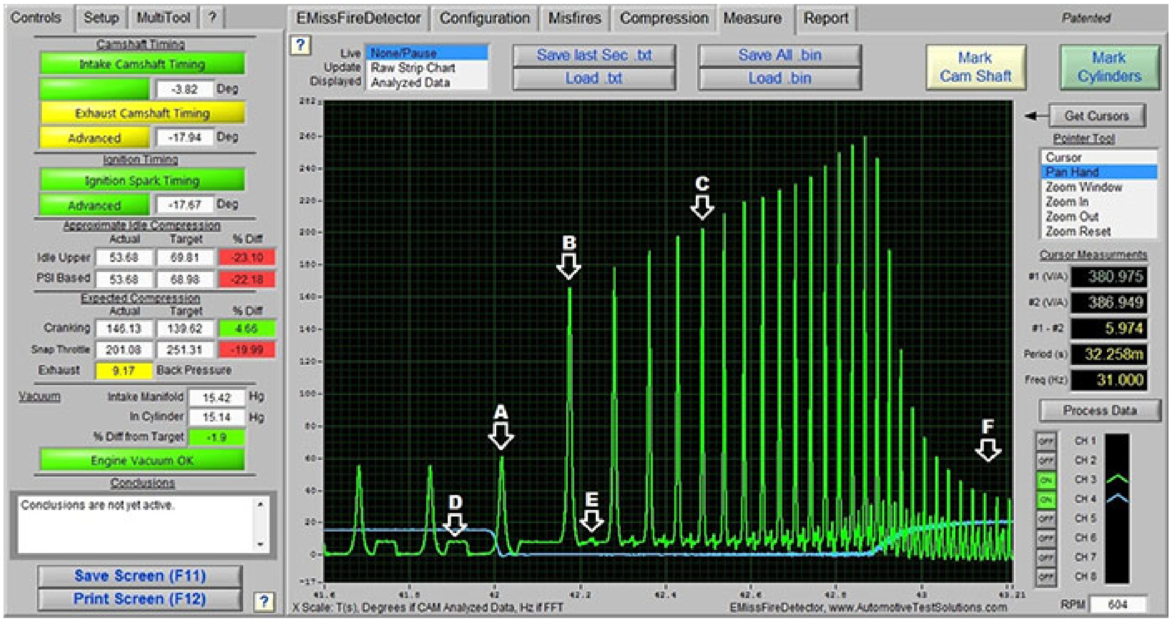

Fig.1

As the throttle is snapped open the restriction is removed from the air induction system. Since the air can now flow freely into the engine the air volume into the engine increases. This increased volume changes the pressure within the cylinder. The first pressure changes that we will analyze within the cylinder can be seen at point A which is with a closed throttle at idle and at point B which is at WOT. At point A the peak pressure is 60 psi and at point B the peak pressure is 165 psi. This pressure difference is greater than double that of the idle pressure with an increase of 105 psi and occurs within one fire cycle or 720 degrees of crankshaft rotation. Additionally the pressure at point B should be equal to or greater than the cranking compression pressure of a good cylinder. When looking for a cylinder that is leaking, point B is a good indicator due to the piston velocity still being low. As the speed of the engine increases the pressure will also increase as can be seen at point C. At point C the peak pressure is 205 psi which is a difference of 40 psi from point B and 145 psi from point A. During the snap throttle event the peak pressure should increase approximately by double within the first fire cycle, and approximately three times by the fifth fire cycle. It is important to note that if the engine is running poorly the throttle valve or idle speed control will allow more air into the engine in order to keep the engine at a target idle speed. This In turn will allow a higher peak idle pressure within the cylinder. Addition some drive by wire throttle control system may not allow the throttle to open rapidly.

When looking at the pressure changes within the cylinder it is best to think about the pressure changes as volume changes. In order to have pressure you must have volume and something that the volume can push against. This idea of volume and pressure can best be seen in Boyle’s ideal gas law.

Boyles law states; where P is the pressure of the gas, V is the volume of the gas, and k is a constant

The amount of matter in a closed system is always constant but if the area (volume) that encloses the matter changes, the force (pressure) changes in proportion. The equation shows that as volume increases the pressure of the gas decreases in proportion. Similarly, as volume decreases the pressure of the gas increases as can be seen in figure 2. If the temperature of the contained gas changes the volume of the gas will also change. The reason that air “expands” when heated is that heat energy causes the air molecules to move faster. Faster moving particles take up more space - larger volume. Cool air “contracts/condenses” for the exact opposite reason. The particles do not have as much energy to rapidly move around taking up space, so they can be closer together - less volume.

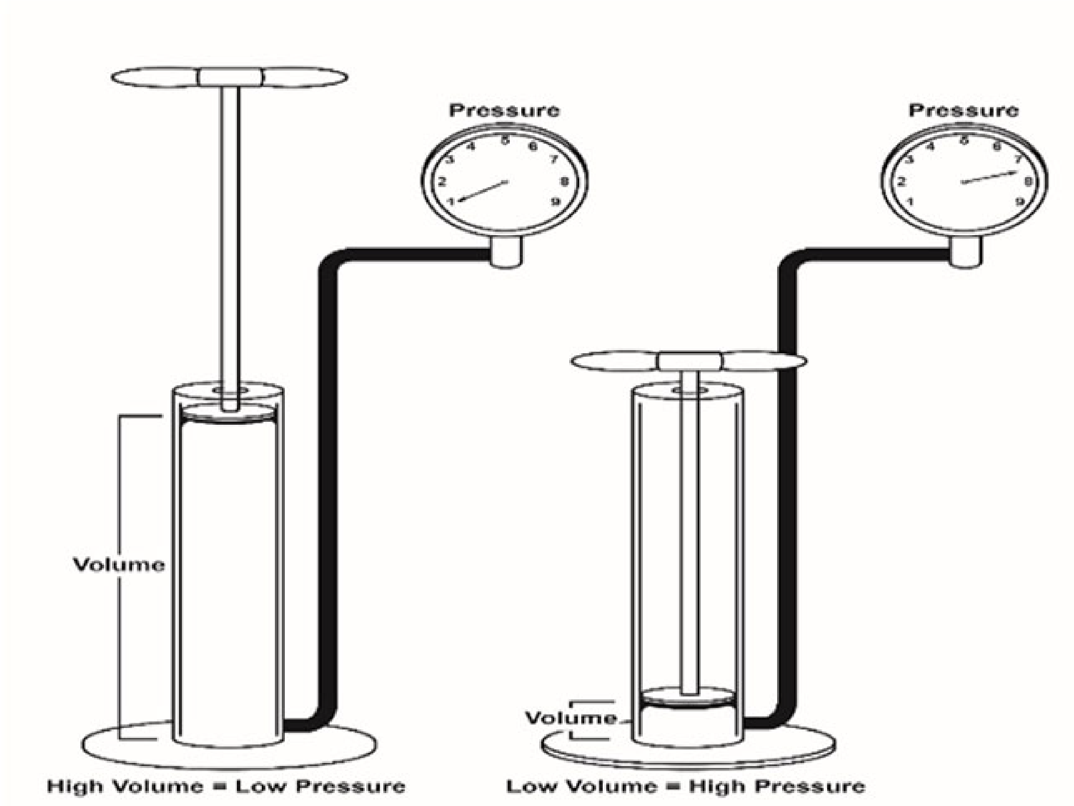

Fig.2

The question is, why would the peak pressure be greater under snap throttle compared to the cranking peak pressure? During cranking the swept volume of the cylinder has more time to fill so the volumetric efficiency of the cylinder is at its highest point. With more volume contained within the cylinder the peak pressure should be at its highest point as well, however this is not the case. During engine crank the engine Revolutions Per Second (RPM) are approximately 150 to 250. During a snap throttle event the RPM can be 2000 to 3000. This increase in the engine's RPM is what allows the peak pressure to increase. As the engine spins faster the pistons velocity is increased, this kinetic energy from the piston is put into the air volume contained within the cylinder. As the piston moves up in the cylinder the air molecules hit the piston crown thus being accelerated. These accelerated air molecules how hit one another creating heat. This increase in temperature allows the air volume within the cylinder to increase as well, thus the peak cylinder pressure increases; more volume = more pressure, less volume = less pressure.

The next pressure change that we will examine is at point D and point E of figure 1. Point D is referred to as the exhaust plateau. This plateau is created by the intake vacuum. When the throttle is snapped open, as can be seen by the blue manifold vacuum trace dropping, the exhaust plateau at point E drops as well. This is due to the loss of manifold vacuum caused by the atmospheric pressure filling the intake manifold in the absence of the throttle restriction. Since the plateau is created by the engine vacuum, as the vacuum goes up or down the exhaust plateau follows the vacuum and will also move up or down. At point F the throttle valve is rapidly closed after the snap throttle event. The engine rotating 2000 to 3000 RPM and the throttle quickly closing creates a very high vacuum condition. This high vacuum causes an engine pumping loss that will slow the engine down quickly. Additionally note that the peak pressure drops lower than the idle peak pressure. This is due to the engine having a higher RPM with the throttle valve closed. In this condition there is less time to fill the cylinder so less air is sealed within the cylinder, thus a lower peak pressure.

In figure 3 a snap throttle waveform is shown. At point A the peak idle pressure is 50 psi. After the snap throttle event the peak pressure is only 35 psi, this is a difference of 15 psi. It is important to analyze the pressure recovery after the snap throttle event. Since the engine RPM has been increased, this energy effects the engine components. Such things as valve springs and lifters may fail with increased energy applied to them. In this example the oil pressure is increased during the snap throttle event. This allowed the lifters to pump up creating a pressure loss within the cylinder thus creating a misfire. This engine had an oil cleaner detergent run through it. This treatment cleaned the lifters fixing this misfire condition.

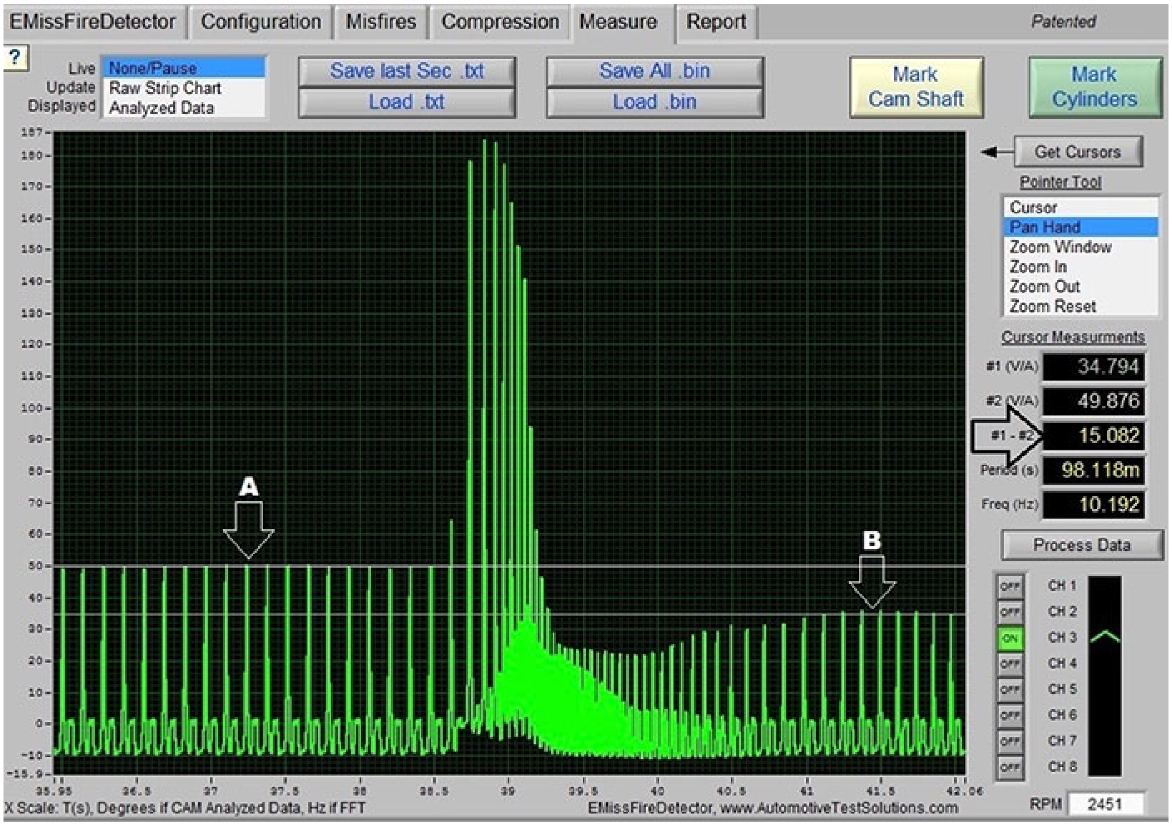

Fig.3

There are two basic snap throttle pressure waveforms as can be seen in figure 4 and 5. Figure 4 is produced from a normal flow snap throttle pressure waveform. Figure 5 is produced from a high flow snap throttle waveform. In a normal flow pressure waveform the air moving through the engine has a slight restriction due to the engine geometry. In the high flow engine design there are less restrictions to the air flow moving through the engine.

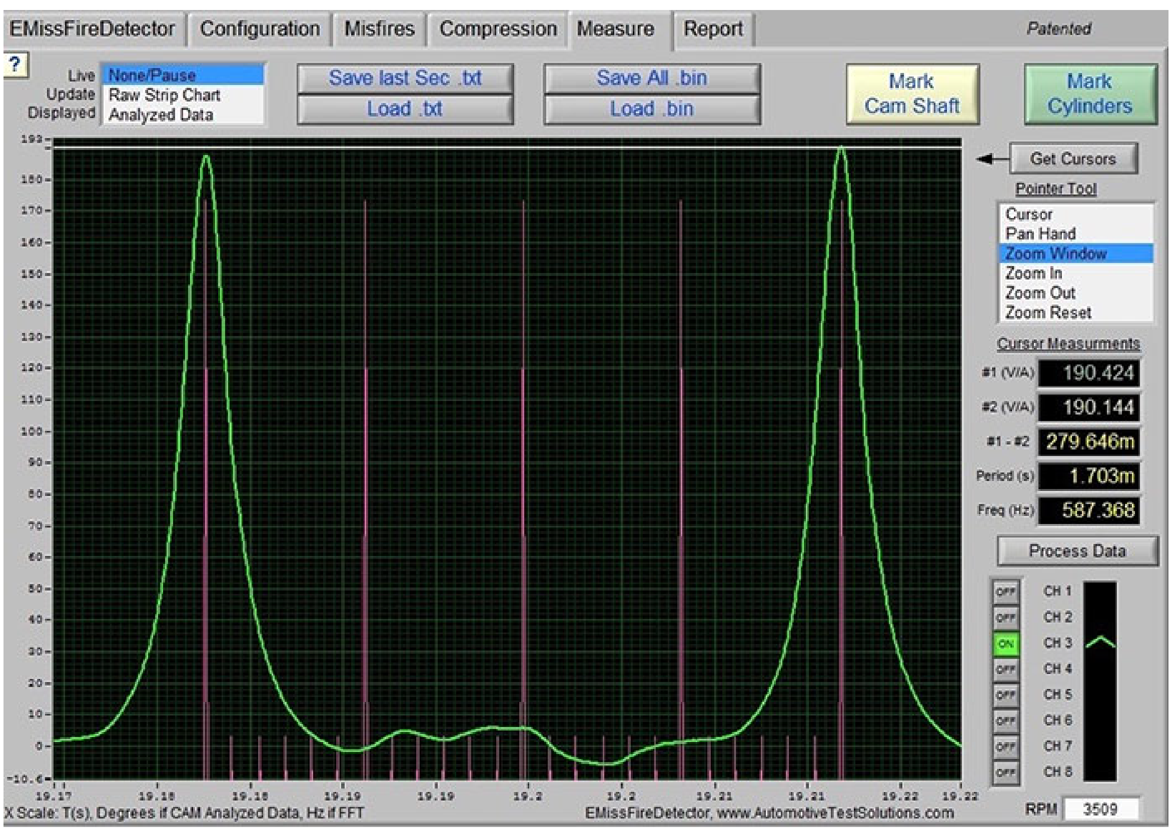

Fig.4

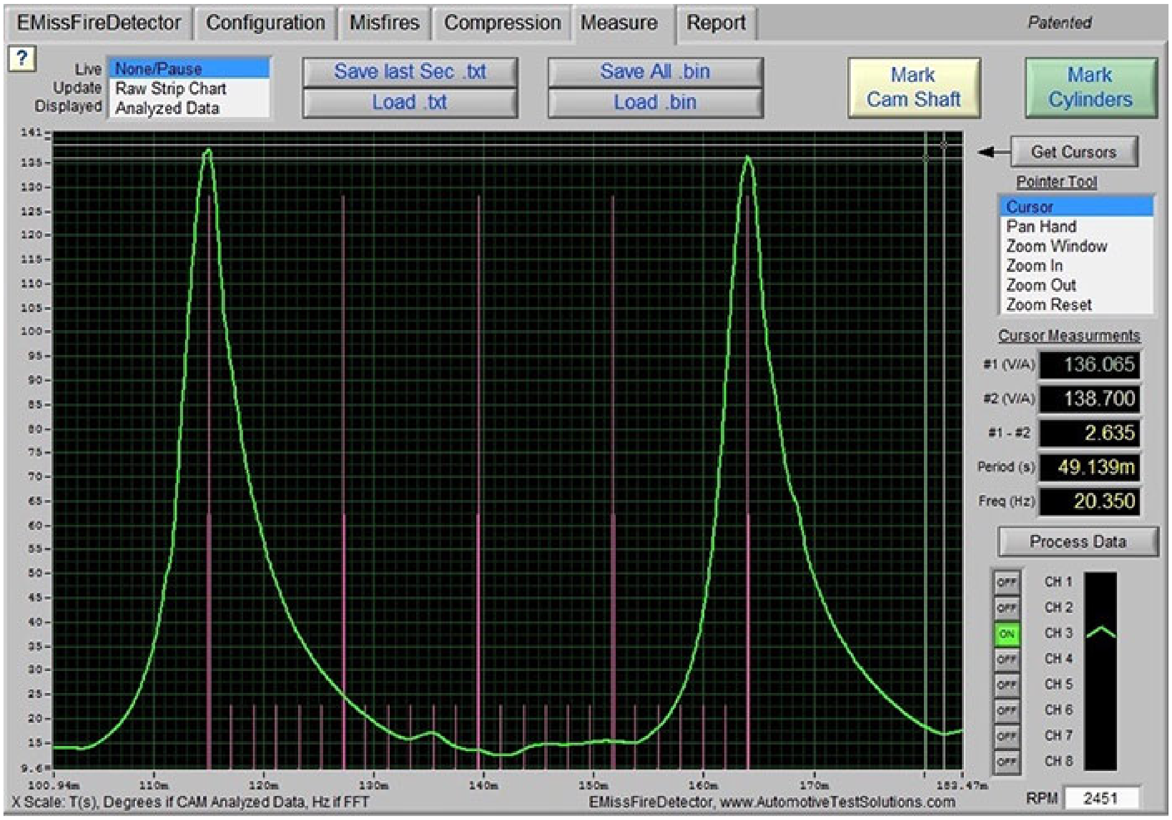

Fig.5

Engine air flow resistance or pressure drop is created by volume against area. The greater the volume the greater the pressure. In an engine exhaust system there is a channel or area that the wasted exhaust gases must pass through. This base exhaust gas has thermal energy that is trying to expand the gas as it is forced out of the combustion chamber into the exhaust port. This means that the volume of the base exhaust gas is increased by the temperature. At low throttle setting the volume of this base exhaust gas is low, as the throttle is increased the volume of this base exhaust gas is also increased. This volume must pass through the exhaust area of the engine.

There are two forces at work as the combustion chamber is being scavenged. The first is the force from the upward piston movement under exhaust, this is forcing the volume out of the combustion chamber. The second is from the energy of the exhaust moving through the area of the exhaust. If the exhaust has mass, which it does, and there is acceleration of the exhaust gas, which there is, there is energy. This energy creates a siphon effect that pulls the exhaust gas out of the combustion chamber. In order to create this siphon effect the velocity of the exhaust gas must be as high as possible. This means that when the engine is being designed the port area will be calculated for the range that the power will be produced. Most passenger vehicles will be operated below 40% throttle for approximately 90% of the vehicle's life. So the velocity of the exhaust gas will be set by decreasing the exhaust area. This will increase the speed of the exhaust gas at a lower throttle setting and at a lower RPM. This is the normal flow geometry design for an engine and will increase the power of the engine where the engine's operating range will be. However this will now provide resistance (back pressure) to the exhaust gases at high volumes or loads. In a high flow geometry design this flow rate is set to produce greater power at a higher RPM range. The design of the engine geometry is always a compromise.

In figure 6 the snap throttle waveform is showing a high backpressure from a restricted exhaust system. At point A the exhaust valve opens and the in-cylinder pressure immediately rises. This is due to the exhaust backpressure being higher than the in-cylinder pressure. Since a high pressure has more force it will always move to a low pressure that has less force. It is important to measure the pressure waveform correctly. This is done by measuring the pressure at the point the exhaust valve opened at point A, and then measuring to the highest pressure obtained between 30 – 60 degrees after BTC shown at point B. This pressure difference should not exceed 8 psi, most engines will have a pressure difference of 3-6 psi. By a 10 psi difference in pressure from point A to point B there will be a power loss associated with the engine. Figure 6 shows that there is a 23 psi difference clearly showing a restriction to the exhaust flow. On this vehicle the exhaust flow restriction was caused by a plugged catalytic converter. This technique will show a very slight restriction within the exhaust where the power of the engine drops off above 5000 to 6000 RPM.

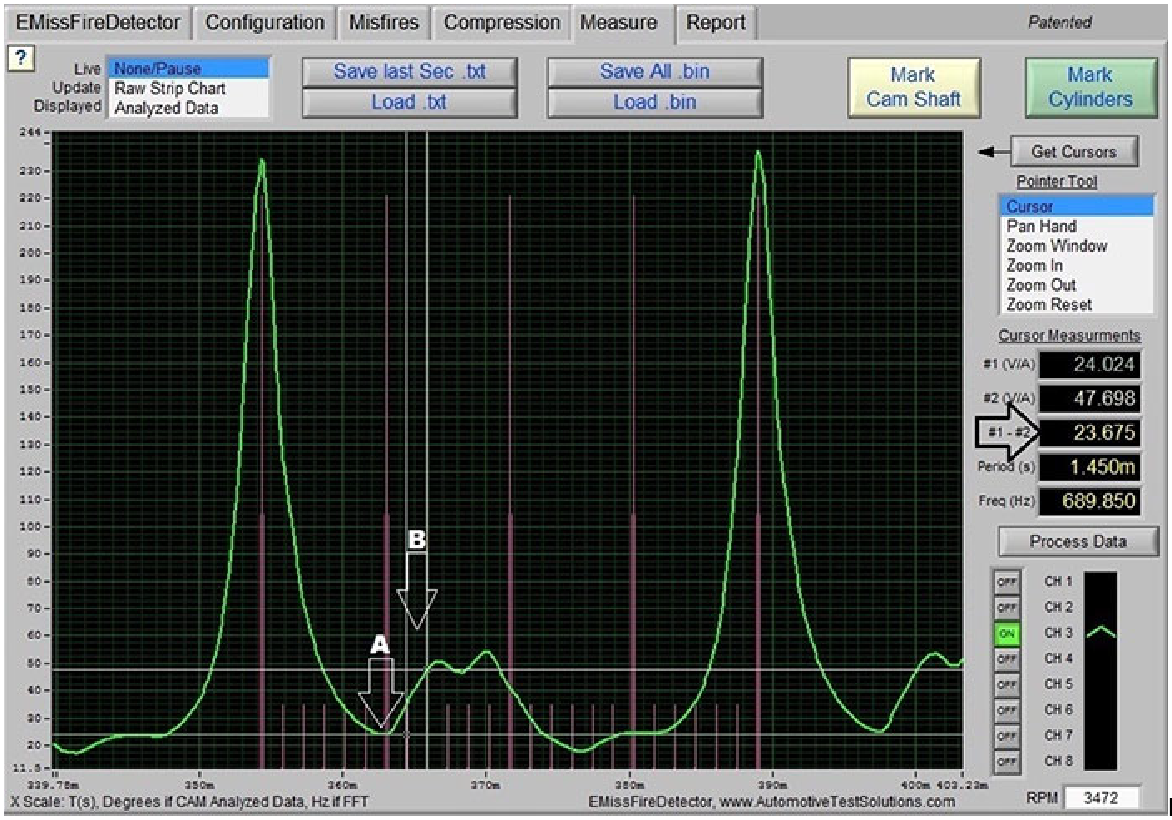

Fig.6

In figure 7 the snap throttle waveform is showing a rise in pressure at point A, this is occurring at the 360 degree mark of crankshaft rotation. The pressure rise at the 360 mark is where the piston is coming very close to the cylinder head as the exhaust stoke is ending. This pressure increase will be associated with things such as advanced exhaust camshaft timing, turbocharged engines, or restricted exhaust ports. It is important to note that the pressure rise occurred late in the exhaust stoke. In this example the pressure at point A has a 28 psi pressure difference. This is caused by the exhaust gas pushing against a turbine in the turbocharger. If the engine has a turbocharger this is normal, however if the engine is not turbocharged there should not be a high pressure buildup at this point.

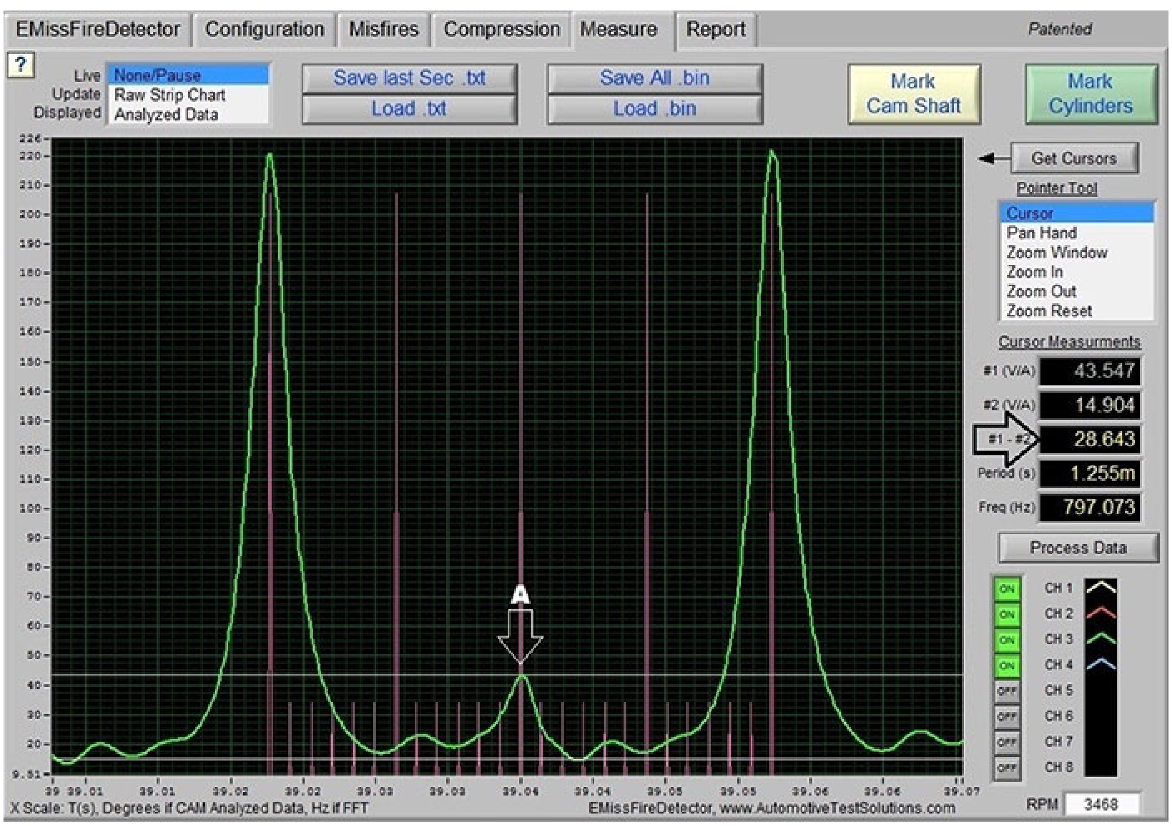

Fig.7

As you increase your knowledge about in-cylinder pressure testing you will wonder how you ever survived without this technique. This is one diagnostic technique your shop needs to master.